ERC

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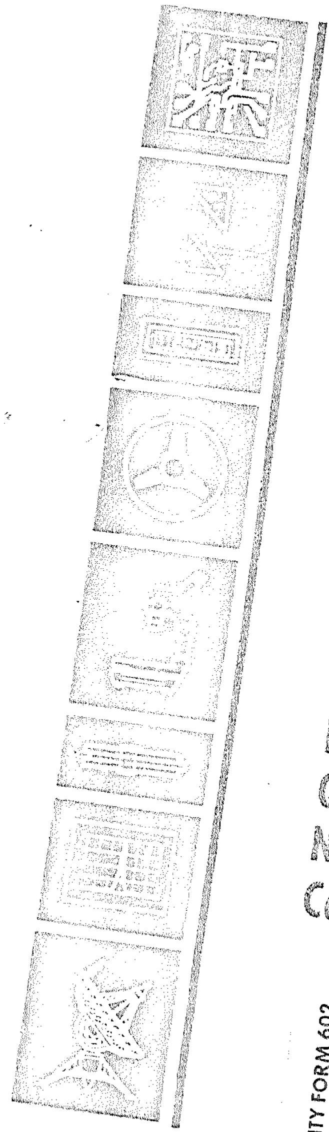


FAILURE ANALYSIS CAPABILITIES

FAILURE MECHANISMS BRANCH
QUALIFICATIONS AND STANDARDS LABORATORY
NASA ELECTRONICS RESEARCH CENTER
Cambridge, Massachusetts

INTRODUCTION

The establishment of a broad capability for fast-reaction analyses of failure mechanisms in electronic components for aerospace applications was included as part of the goal of Program Planning Document 420.1.1 -- Physical, Chemical and Metallurgical Techniques -- in the Failure Mechanisms Branch of the Qualifications and Standards Laboratory at the Electronics Research Center (ERC). It was approved by the Assistant Director for Electronic Components Research on May 12, 1966.

In the preliminary plans for the FY '69 Program, prepared September 6, 1967, Task Area No. 3 -- Quick-Reaction Failure Analysis -- was included as one of the six task areas of the Failure Mechanisms Branch.

This brochure has been prepared to give a more detailed explanation of the capabilities and functional relationships for performing failure analysis within the Failure Mechanisms Branch.

The Qualifications and Standards Laboratory was created to do work which might provide a higher degree of reliability in electronic components used by all NASA Centers. Support requests enable ERC to provide direct aid for immediate and long-term failure problems of concern to all NASA Centers, and also to give ERC an opportunity to visualize the problems being encountered under actual aerospace environmental conditions where the reliability of electronic components spells success or failure in space vehicles. It is therefore understood that the support requests which arise both internally and externally are important functions of all branches.

As indicated in the ERC Program Planning documents, one of the functions of the Failure Mechanisms Branch is to investigate failure mechanisms using a number of different approaches. Basically, these involve studying the physics of failure. The Failure Mechanisms Branch was structured by the choice of personnel, internal research programs, and contract work to provide competence in this area. An integral part of this program is the important function of quick-reaction analysis of failures in electronic components. To this end, specialized equipment was installed and put into operation for physical, chemical, metallurgical, and electrical analysis. New techniques for these investigations are being brought into use to provide the rapid response to failure problems that should be expected from the Branch.

As an integral part of failure analysis, it is planned that CQS will cooperate with CQF in testing, evaluation, and testing to failure. On the other hand, one of the many functions of CQS is recognized to be long-term testing and evaluation of electronics components. In this respect, it is planned that CQF will perform a support function by providing failure analysis of questionable components. In general, with regard to technical support function relationships with other groups, the Failure Mechanisms Branch will utilize its support, or that of outside contractors, in environmental and most electrical testing.

It is imperative that only trained members of the Failure Analysis team be responsible for all testing performed after the device is decapped. This is required because of the danger of foreign contamination or damage being introduced by the slightest degree of improper handling or storage, which could result in incorrect diagnosis of the original cause of failure.

FUNCTIONAL PROCEDURE FOR FAILURE ANALYSIS IN THE FAILURE MECHANISMS BRANCH

The following procedure has been established for acceptance and follow-through on failure analysis tasks in the Failure Mechanisms Branch.

RECEIPT OF REQUEST FOR ANALYSIS

All requests for failure analysis must be submitted through the Failure Analysis Project Engineer who is responsible for the coordination of tasks.

Upon receiving a request for failure analysis, a "Request for Initiation of Research Task" form (Figure 1) will be filled out. Sign-off by the Failure Mechanisms Branch Chief and the Qualifications and Standards Laboratory Chief is required to initiate the task.

REQUISITES BEFORE STARTING THE ANALYSIS

Before any analysis is performed: (a) a complete history of the device will be assembled and circulated to those concerned; this information is vital in forming a complete and coherent picture; and (b) the Section Heads will collaborate with the Project Engineer in distributing the individual analysis tasks.

PERFORMING THE ANALYSIS

Figure 2 describes, in general, the sequence of tests. Under certain circumstances it may be advisable to eliminate some of them. The Branch Chief has made it clear that rapid performance on requests for failure analysis will take precedence over the in-house research efforts.

REQUEST FOR INITIATION OF RESEARCH TASK

RESEARCH TASK NO.: ____________________ DATE OF REQUEST: ____________

REQUESTED INITIATION DATE: ____________________ DATE DUE: ____________

TITLE: ____

REQUESTED BY: (name, affiliation, address, telephone)

____

PROBLEM:

____

APPROACH:

____

MANPOWER ESTIMATE: ____________________ CHARGE NO.: ____________

RESPONSIBLE INDIVIDUAL: (sign) ________________________________

APPROVED FOR INITIATION: (sign)

Section Head	Chief, Failure Mechanisms Branch	Chief, Qualifications & Standards Laboratory

COMPLETION DATE: ____________________

DISTRIBUTION OF ATTACHED REPORT ON COMPLETED TASK APPROVED BY:

Responsible Individual	Section Head	Chief, Failure Mechanisms Branch

Figure 1.

DISCUSSION OF TEST RESULTS

When the various analytical tasks have been completed, a committee consisting of the Project Engineer, Branch Chief, and Section Heads will review the results and draw the conclusions. This could result in some additional tests being made. It also may lead to the institution of new in-house research to resolve a new type of failure mechanism.

REPORT

The data and conclusions will be assembled by the Project Engineer for final review by the Branch Chief and Laboratory Chief. The final report will require signatures of both the Branch and Laboratory Chiefs. Distribution of the report will depend on the sensitivity of the problem. It is expected that Branch personnel will not provide wider dissemination of the report or any of its contents without first clearing the action with the Failure Analysis Project Engineer.

GENERALIZED PROCEDURE OF THE FAILURE MECHANISMS BRANCH FOR FAILURE ANALYSIS OF SEMICONDUCTOR DEVICES

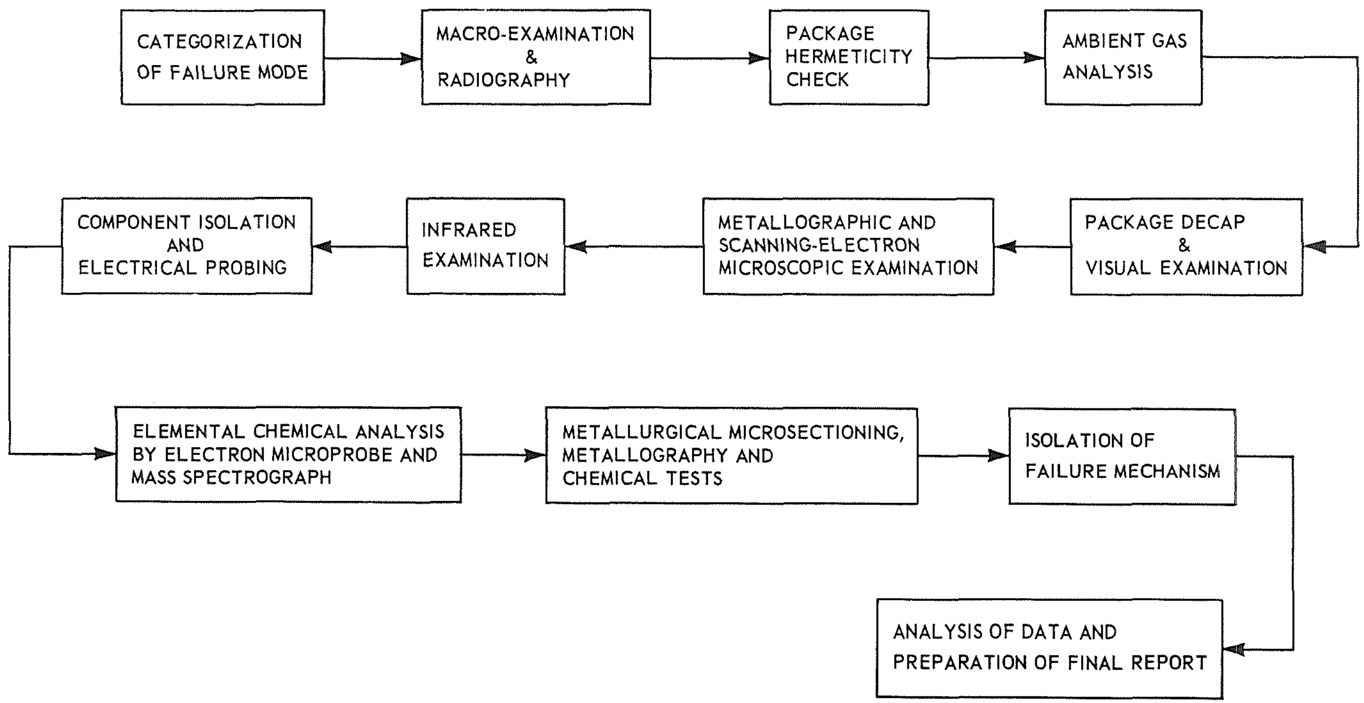


Figure 2.

FAILURE ANALYSIS INSTRUMENTATION

The following instruments and facilities are available for performing failure analysis at ERC.

Bausch & Lomb research and stereo-zoom microscopes

Bausch & Lomb research metallograph

Unitron, Model HM, hot stage metallograph

Hitachi electron microscope * *

Acton Lab MS-64 electron probe X-ray microanalyzer

AMR scanning electron mirror microscope *

JEOL scanning electron microscope * *

Barnes Model 12-910 infrared radiometric microscope

Zeiss interferometer

Faxitron Model 804 X-ray equipment

Norelco vacuum spectrometer for X-ray fluorescent analysis

ARL spectrographic analyzer

Beckman Model IR-10 infrared spectrophotometer

* Presently being developed for NASA by Advanced Metals Research Corporation.

* * To be acquired.

Perkin-Elmer Model 900 gas chromatograph

General Electric Model H-5P halogen leak detector

NRC Model 925 mass spectrometer leak detector

Buehler grinding and polishing equipment

Associated Testing Lab Model SLHE-1-LC temperature chamber

Fisher vacuum oven

Lead tensile strength tester

Electro-glass electrical probing apparatus

Birtcher Model 800 integrated circuit tester

Fairchild Series 400 integrated circuit tester

Birtcher Model 70 semiconductor tester

Fairchild Model 6100 switching time tester

Tektronix curve tracers and oscilloscopes

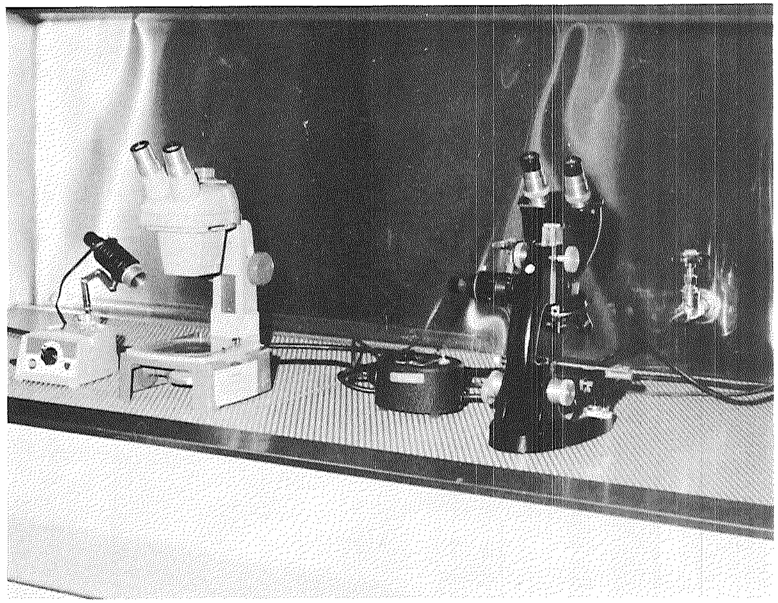
Facilities for performing inorganic and organic chemical analyses

Figures 3 through 20 show the various equipments in use in the Failures Mechanism Branch.

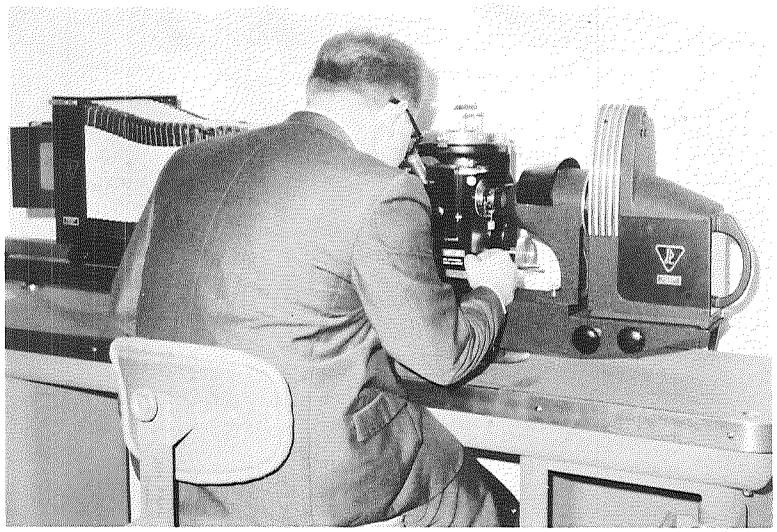
VISUAL MICROSCOPIC EXAMINATION

- Examination of device condition:
  wafer surface,contaminants,
  foreign particles, masking defects,
  oxide defects, metallization irregularities
  mechanical defects and open bonds,
  broken or shorted internal leads, cracked
  dice, cracks in package seal, scratches

- Examination of metallographical cross-section
  specimen for voids, burn marks, diffusion
  irregulants, and intermetallic formations



Bausch & Lomb stereo-zoom microscope (left) and Bausch & Lomb microscope (right) used for low- and medium-power visual examinations and microphotography.

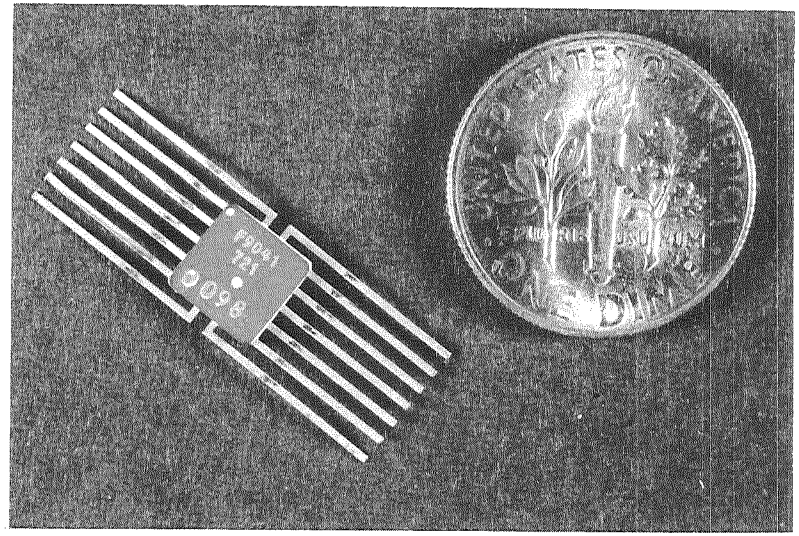


Bausch & Lomb research metallograph used in visual examination and microphotography (25-2000X)

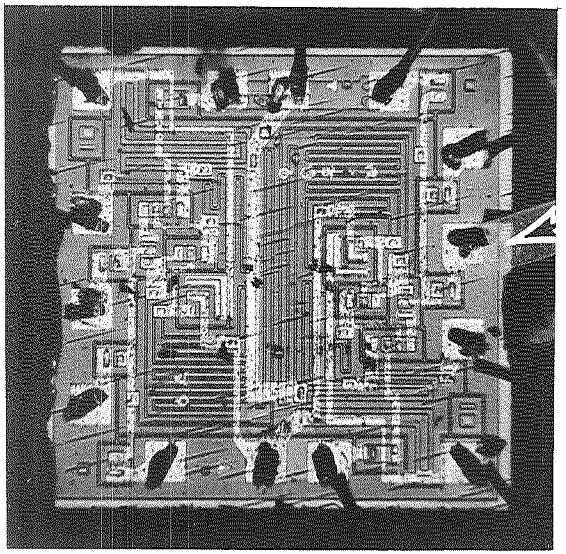
- Bright field
- Dark field
- Polarized light
- Phase contrast

Figure 3.

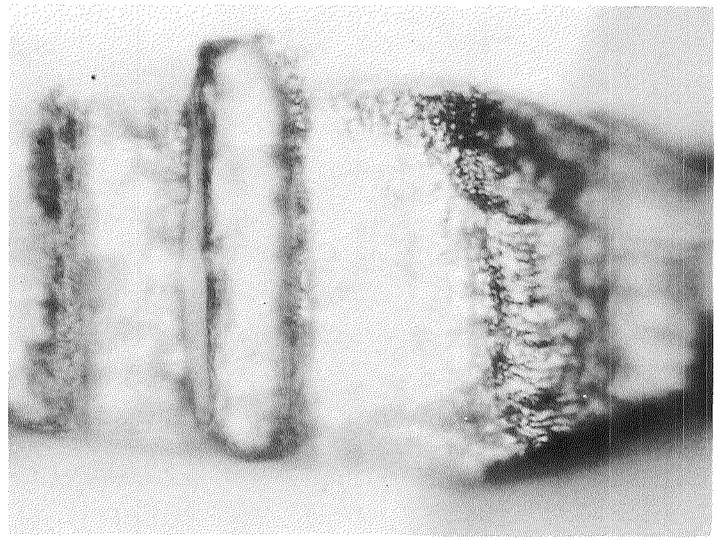
VISUAL MICROSCOPIC EXAMINATION



Integrated circuit flat-pack



Integrated circuit topograph



Optical microphotograph of bond A showing a microcrack in the lead material (1500X)

Figure 4.

VISUAL MICROSCOPIC EXAMINATION
SCANNING ELECTRON MICROSCOPE

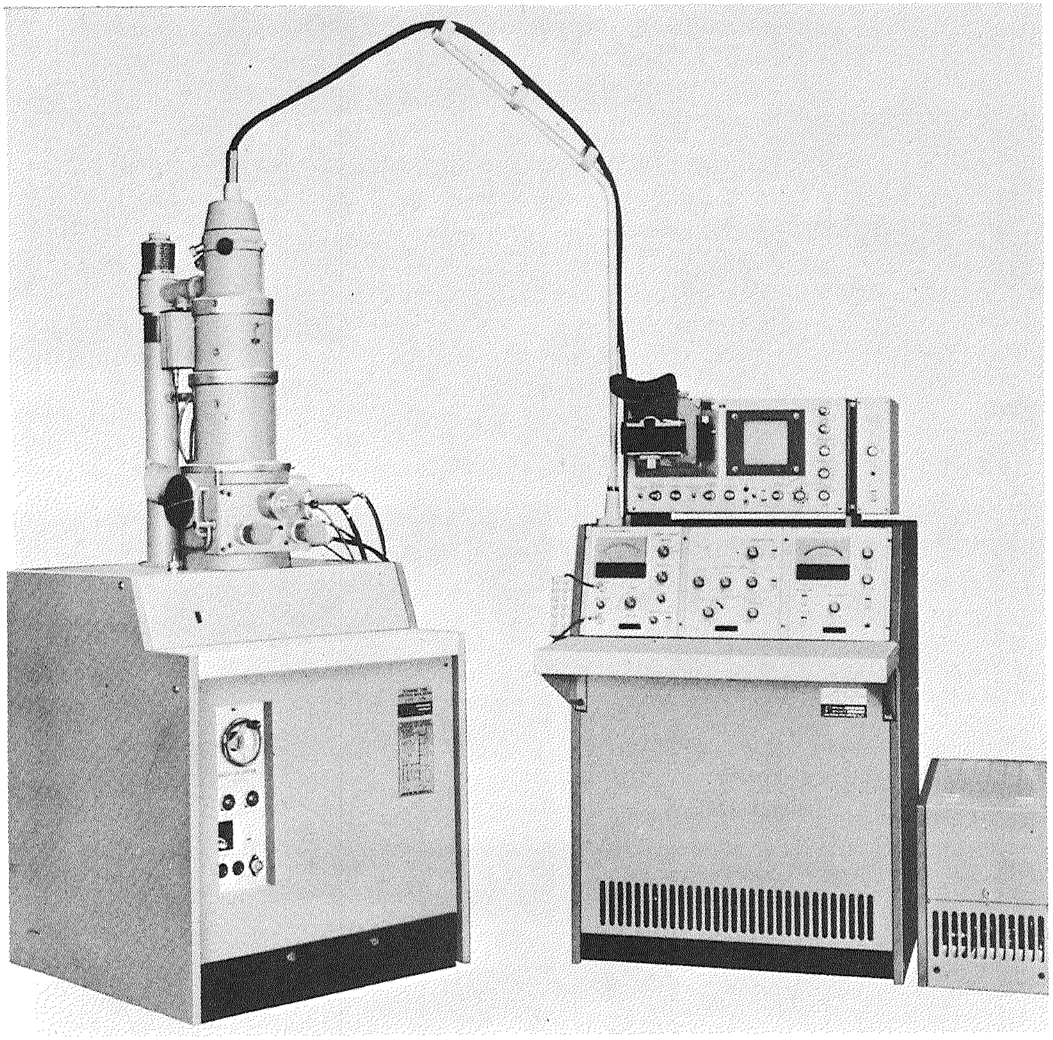
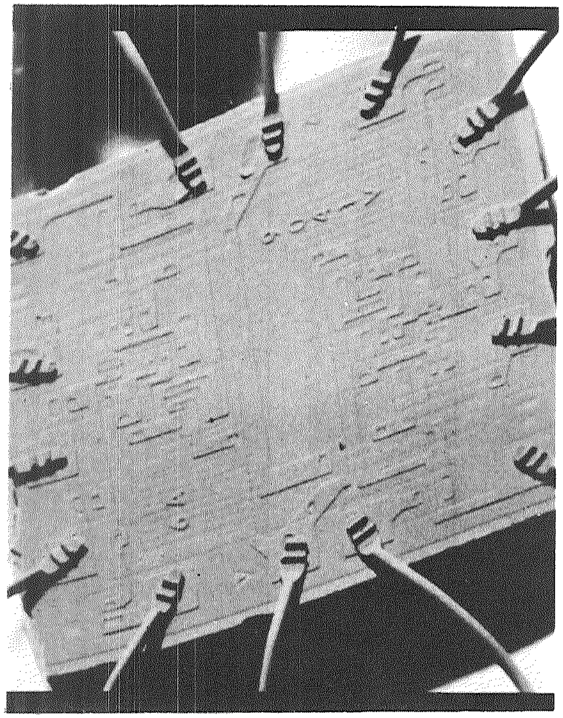


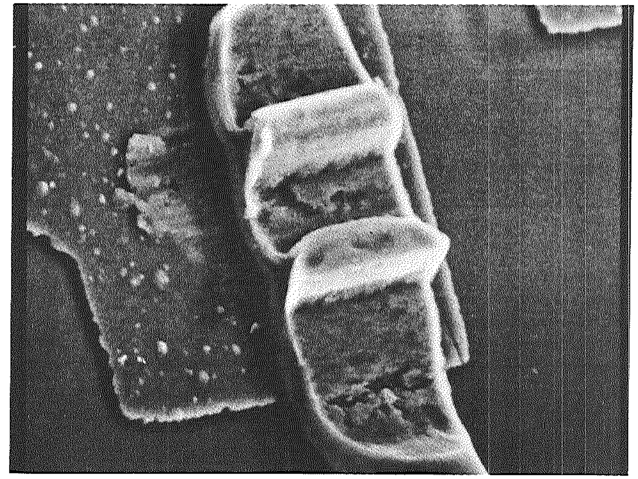
Figure 5.

VISUAL MICROSCOPIC EXAMINATION

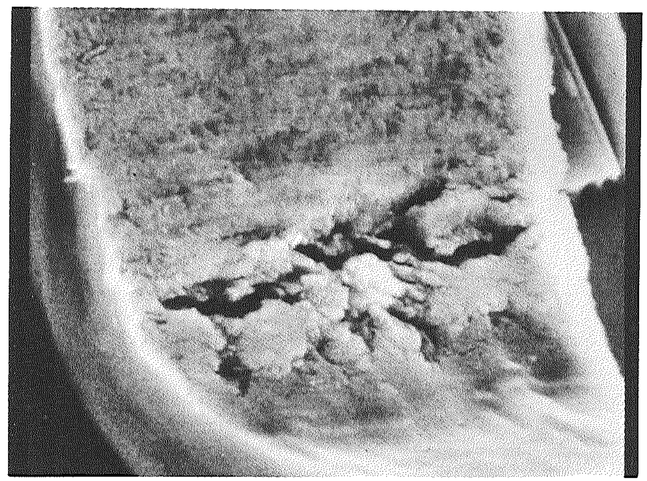
SCANNING ELECTRON MICROSCOPE



Integrated circuit topograph (60X) obtained by scanning electron micrography



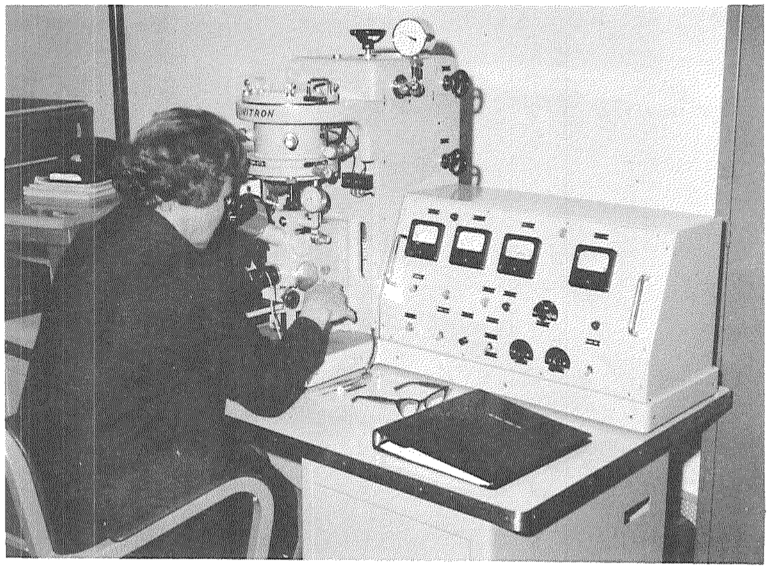
Scanning electron micrograph of bond A showing a microcrack (510X)



Scanning electron micrograph of bond A showing a microcrack (2300X)

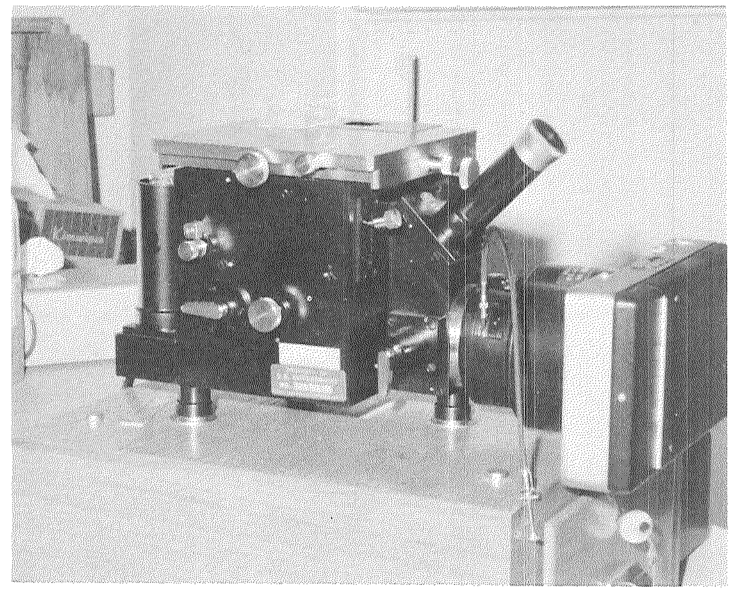
Figure 6.

VISUAL MICROSCOPIC EXAMINATION



Hot stage Metallograph

- Contaminant identification by melting point and reactivity
- Metal interdiffusion Al-Au, Mo-Au
- Whisker growth
- Grain growth
- Surface diffusion of metal films



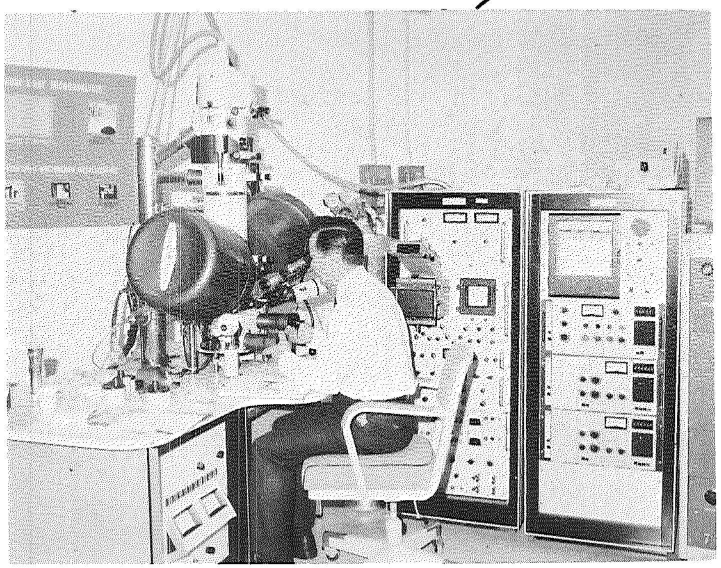
Zeiss Interferometer

- Oxide and metallization surface topography
- Stacking defects
- Film thickness variations

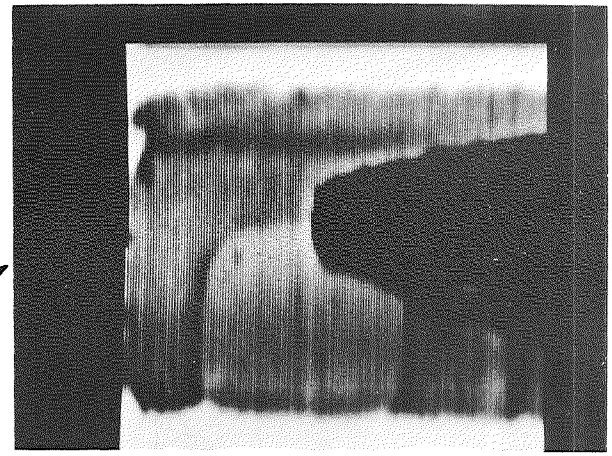
Figure 7.

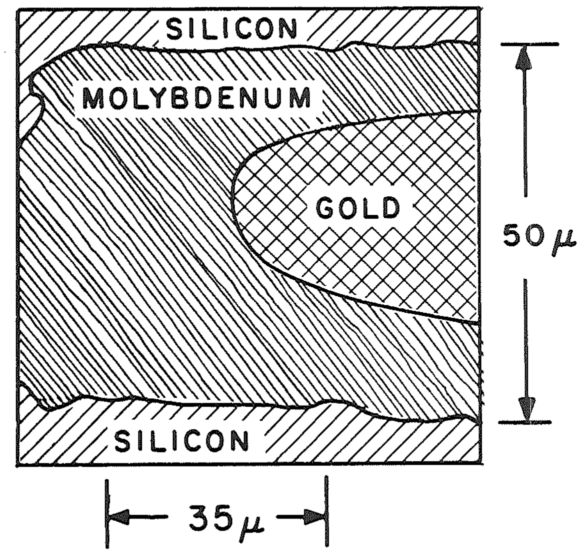
VISUAL MICROSCOPIC EXAMINATION - - ELECTRON MICROPROBE

- Detection of contaminants
- Elemental chemical analysis
  - — contaminants
  - — dopant and dopant concentration
  - — intermetallic compounds
- Cracks, flaws, voids, pits
- Junction irregularities



Electron Microprobe

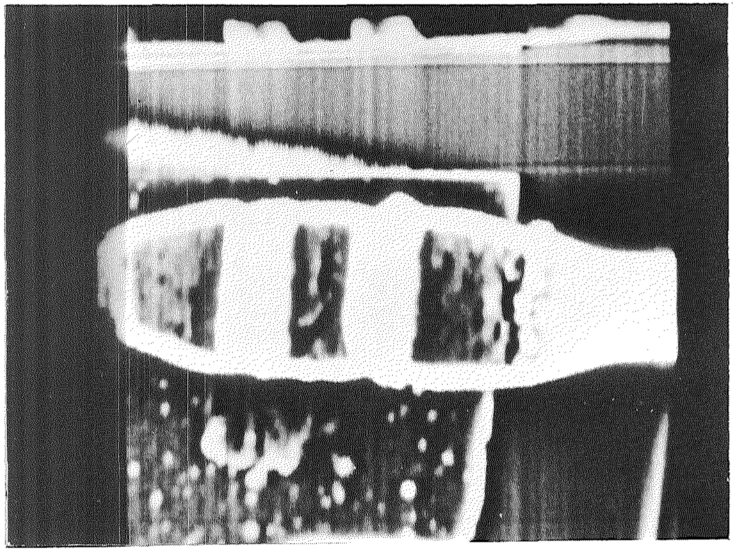




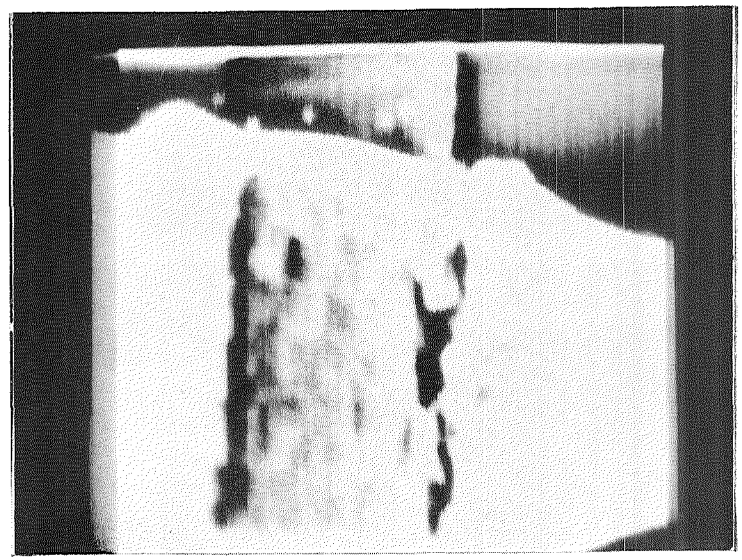
Specimen current raster scan showing gold and molybdenum metallization on an integrated circuit (Sample 26A). Selected areas of gold have been removed to expose the underlying molybdenum barrier layer.

Figure 8.

VISUAL MICROSCOPIC EXAMINATION - - ELECTRON MICROPROBE



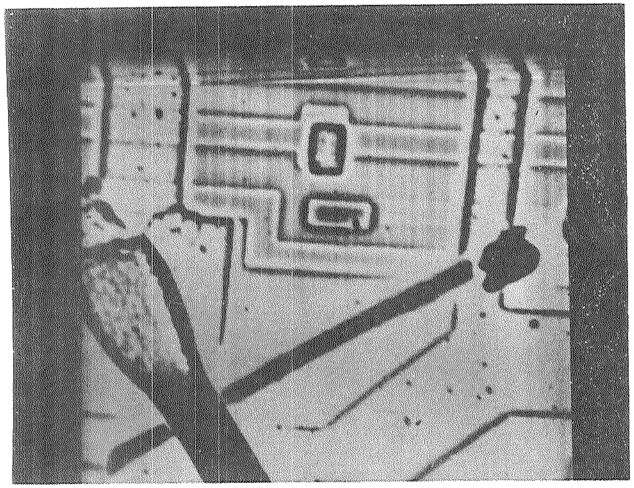
Electron microprobe scanning image of bond A showing a microcrack (560X)



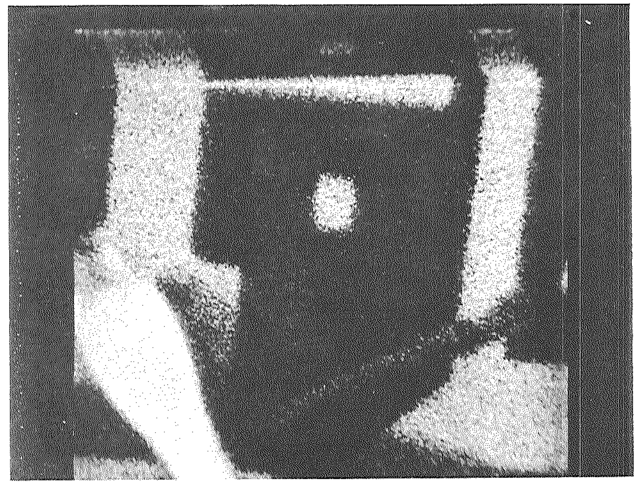
Electron microprobe scanning image of bond A showing a microcrack (1430X)

Figure 9.

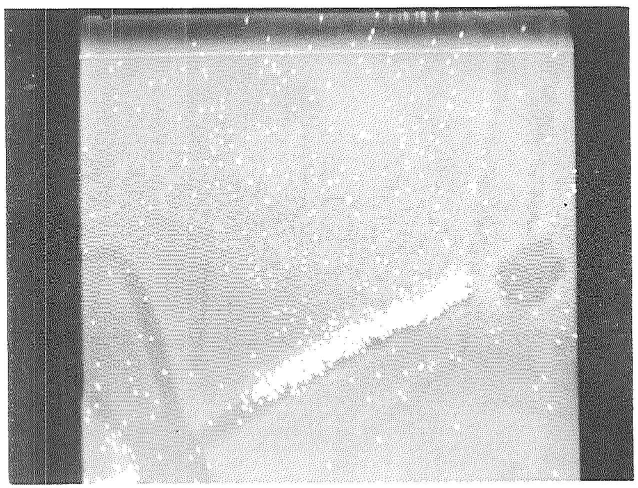
IDENTIFICATION OF CONTAMINANTS BY ELECTRON MICROPROBE ANALYSIS



Electron image of contaminated area
on an integrated circuit



Aluminum — K alpha X-ray image

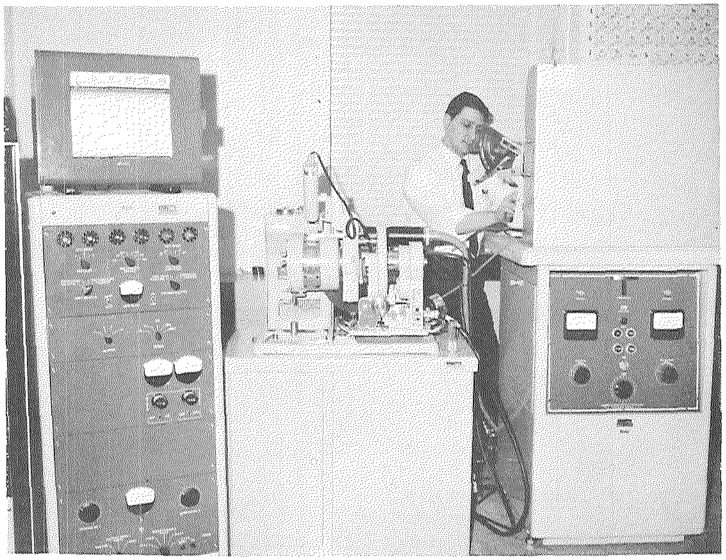


Combined electron and calcium X-ray image

Combined electron and iron X-ray image

Figure 10.

X-RAY DIFFRACTION



Examination of X-ray diffraction patterns provides:

- Identification of various phases, construction materials and contaminants
- Information about quality of crystals, size, shape and distribution of particles or crystallites
- Information on the nature and distribution of grain boundaries and crystallographic defects such as dislocations and stacking faults
- Detection and measure of stresses in any crystalline material

EMISSION SPECTROSCOPY

- Qualitative and quantitative analysis of metals
- Determination of trace impurities

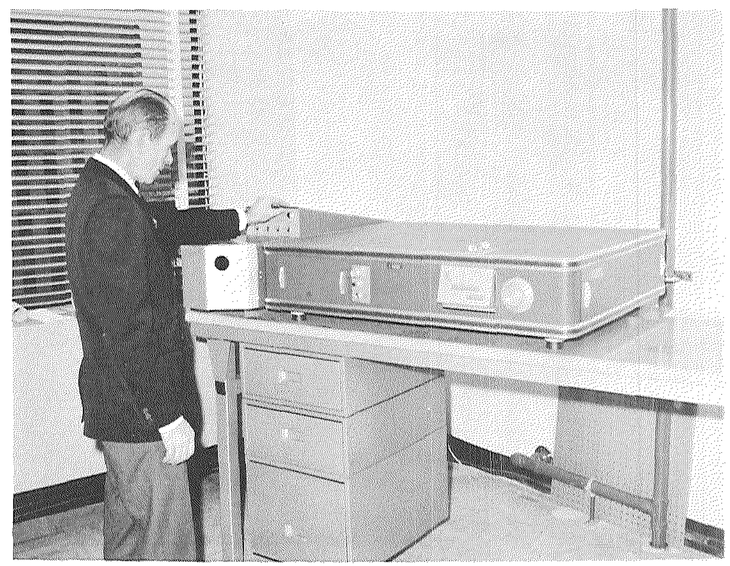
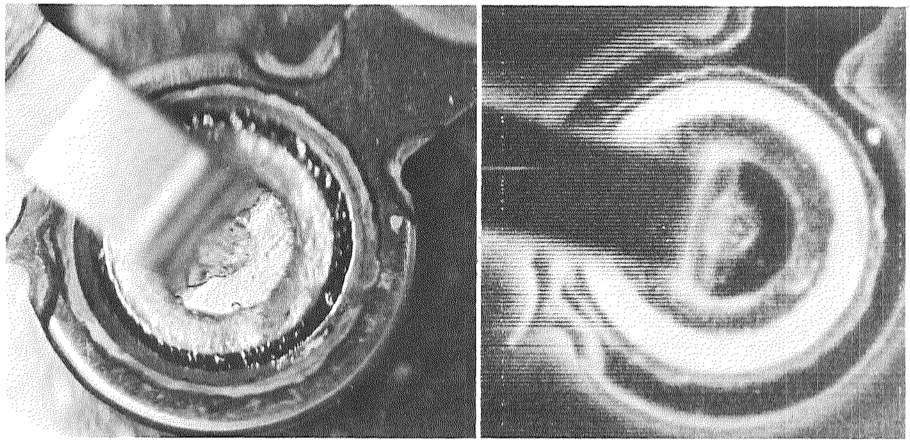


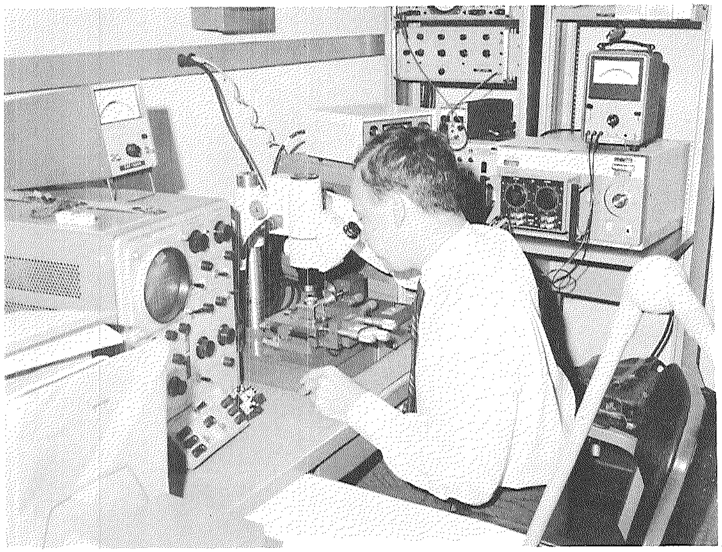
Figure 11.

INFRARED RADIOMETRY

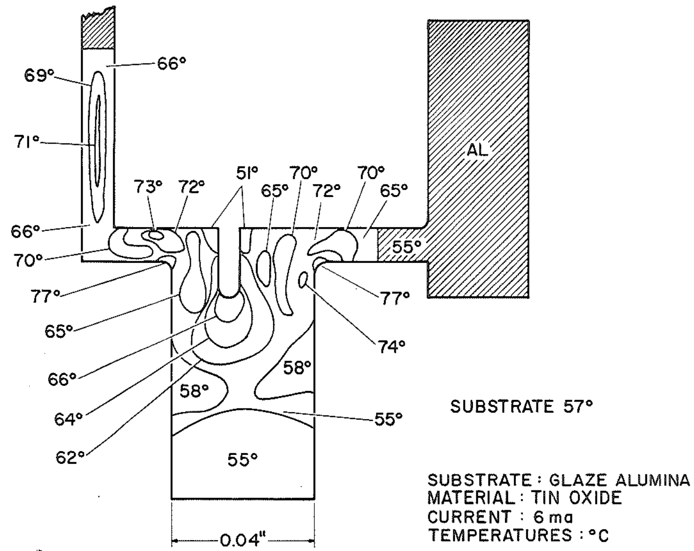
- Non-destructive thermal distribution profiles
- Detection of:
  - Hot spots due to voids
  - Hot spots due to insufficient conducting area
  - Hot spots due to scratched or damaged metallization
  - Hot spots due to dislocation or stacking faults



Power Transistor Junction – Thermomicrograph



Barnes Infrared Radiometric Microscope

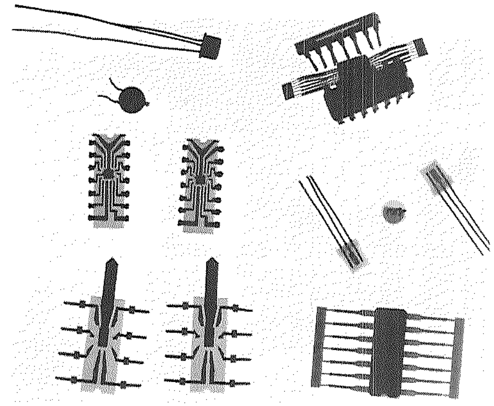


Film Resistor – Hand-Plotted Isotherms

Figure 12.

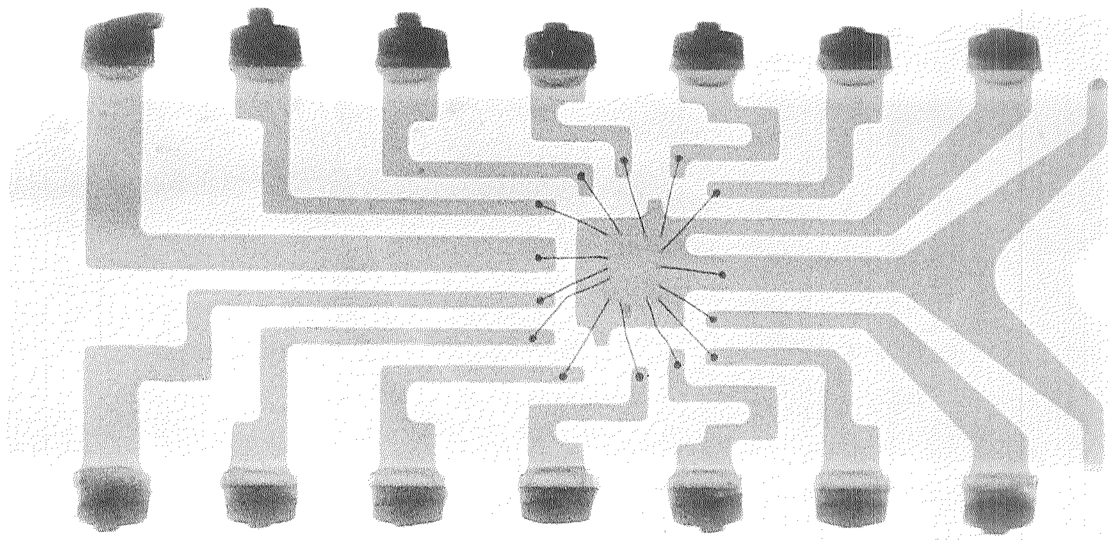
RADIOGRAPHIC EXAMINATION

- Device internal construction
- Voids in welds and bonds
- Contaminant and other foreign particles
- Cracks and flaws
- Mechanical defects and misalignment of parts.



X-ray photographs of various semiconductor devices

Faxitron X-ray equipment

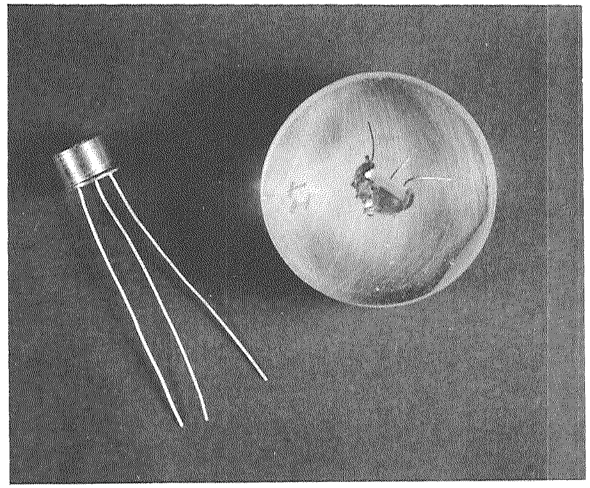


Enlargement of X-ray photograph (8x)

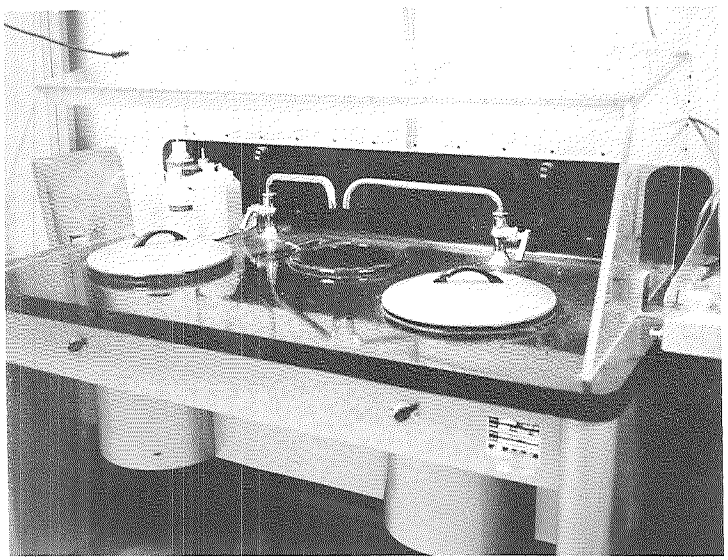
Figure 13

METALLOGRAPHICAL LABORATORY

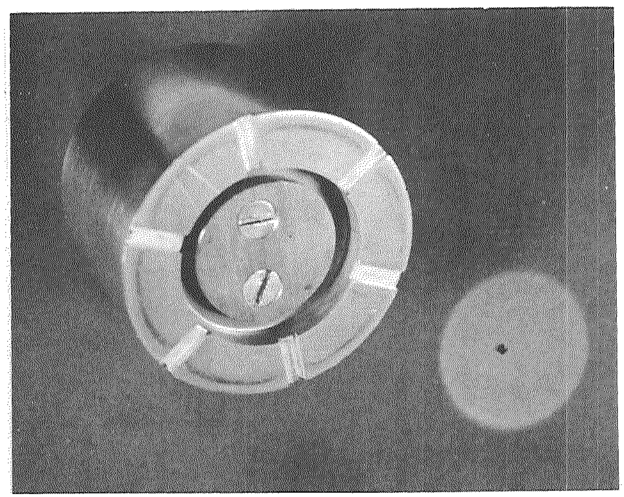
- Cross-sectioning of the device allows the examination and study of the
  - Internal structure of the device (junction definition, depth, uniformity)
  - Intermetallic interfaces between the chip and the bond and chip and the header
  - Cracks, flaws, voids, burn, and over-heating marks
  - Plating thickness and layer uniformity
  - Material grain structure



Transistor before and after molding in clear epoxy.



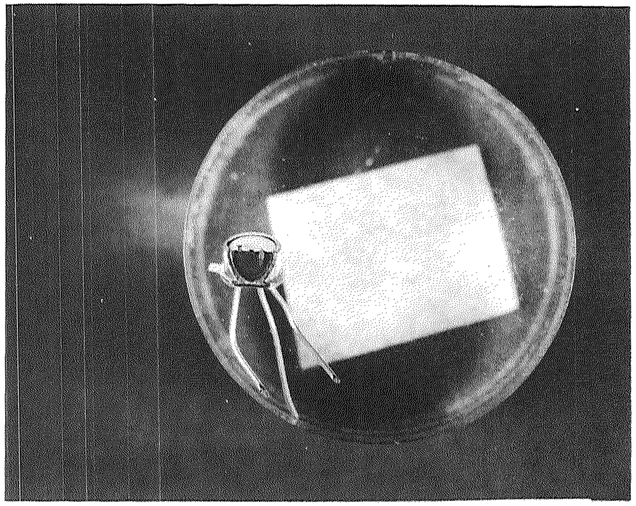
Buehler grinding and polishing equipment



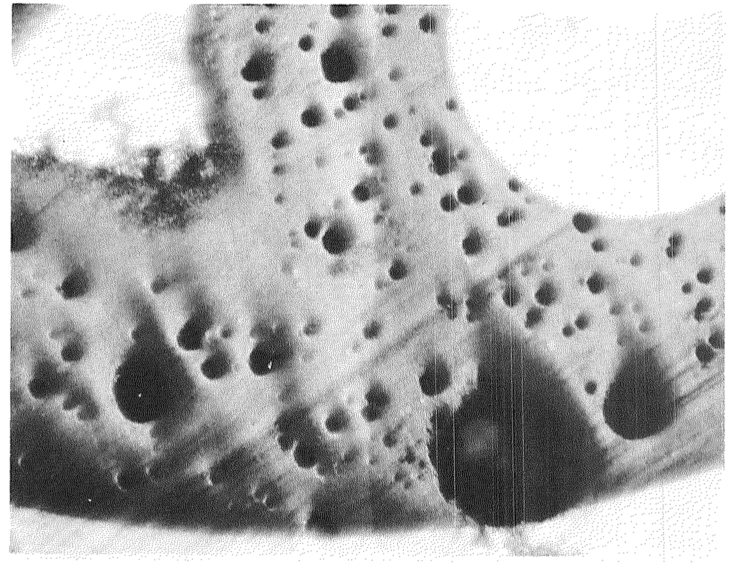
Thin wafer of silicon is mounted on an angle sectioning fixture. This method provides expanded view of the cross-section.

Figure 14.

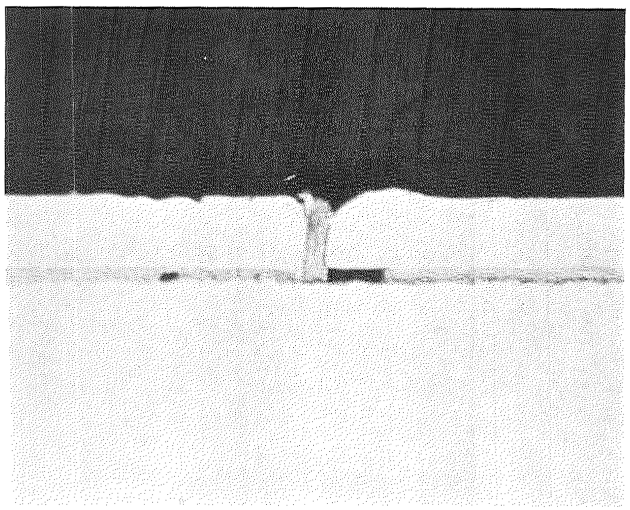
METALLOGRAPHICAL LABORATORY



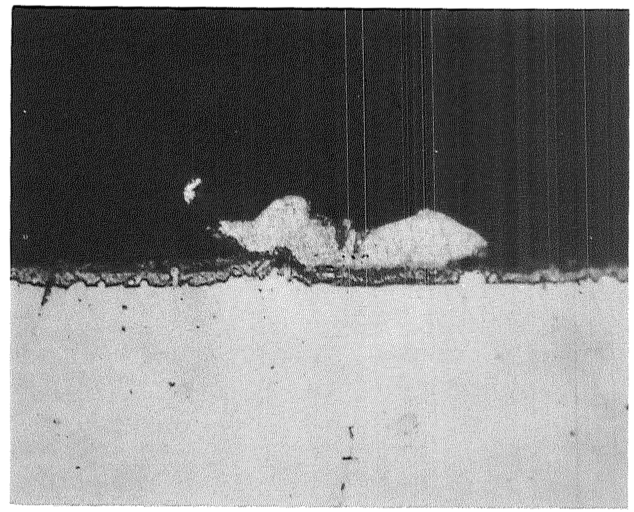
Metallographical Specimen



Microphotograph of the transistor header cross-section revealing extreme porosity of the glass seal (100x)



Microphotograph of the integrated circuit wafer-header assembly revealing substantial amount of voids.



Purple plague formation at post bond of an integrated circuit.

Figure 15.

HERMETICITY CHECK

Gross and fine leaks in packages
Leakage paths, cracks, pores

GROSS LEAK TEST

Because of the deficiencies of the conventional bubble test, a considerable effort is being expended by this and other laboratories to devise new gross leak test methods.

Fluorescent penetrating dye used in conjunction with "black" light is useful in observing leakage paths, cracks, and pores.

FINE LEAK TEST

Helium leak tester
Leak rates as low as 10^{-11} are determined.

Figure 16.

HERMETICITY LEAKS AND AMBIENT GAS ANALYSIS

GAS CHROMATOGRAPH

- Detection and analysis of abnormal package ambients.
- Leak detection by presence of air or test fluids in the ambient.

Figure 17.

LEAD TENSILE STRENGTH TEST

- Capability of determining tensile strength of fine wires under controlled conditions.
- Permanent recording of breaking point and breaking strength.

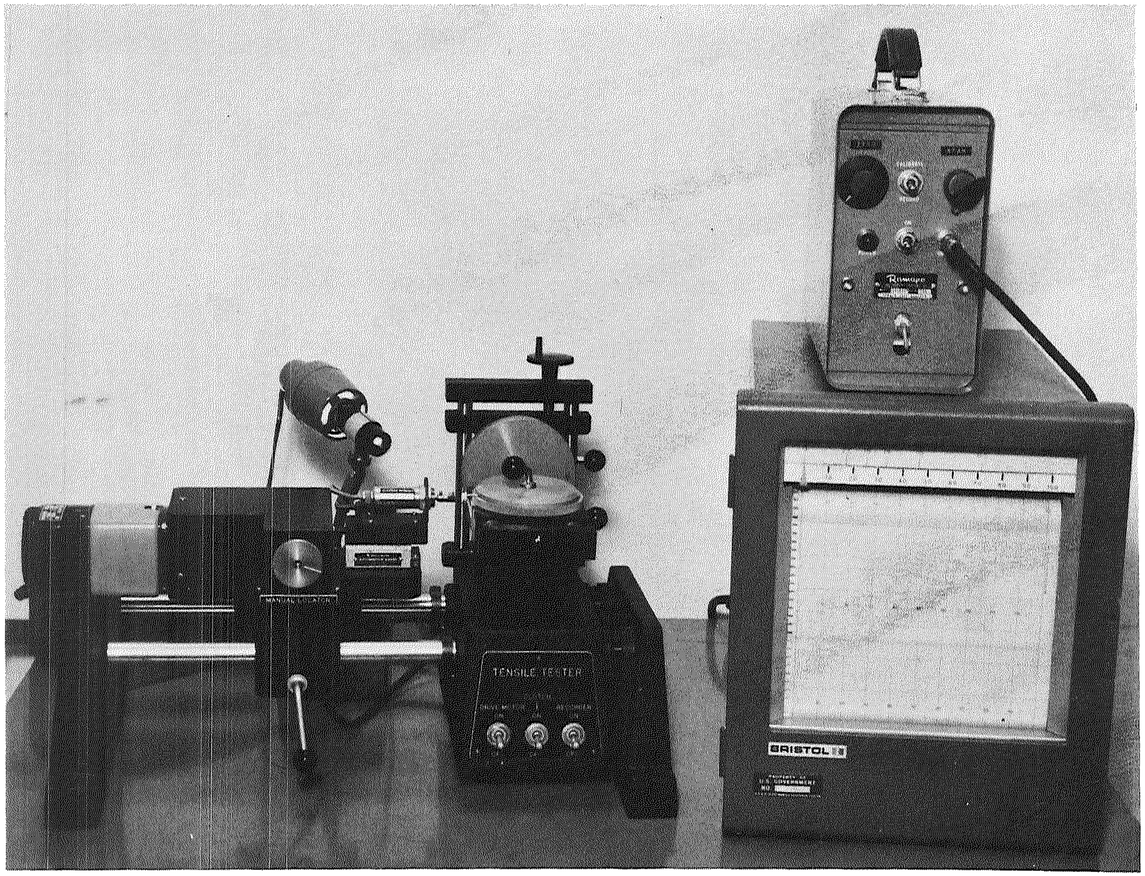
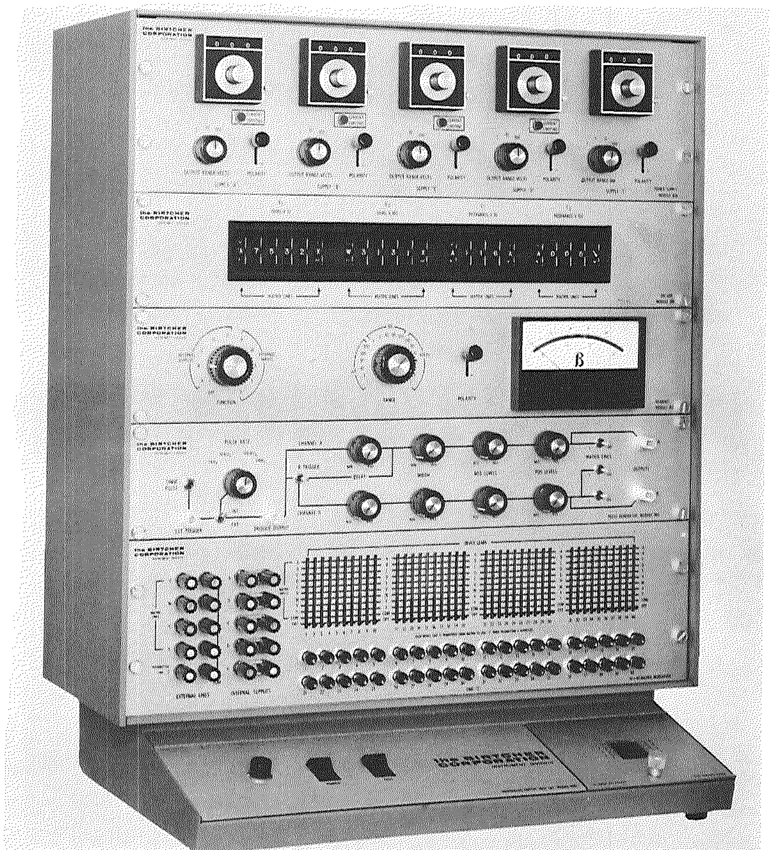
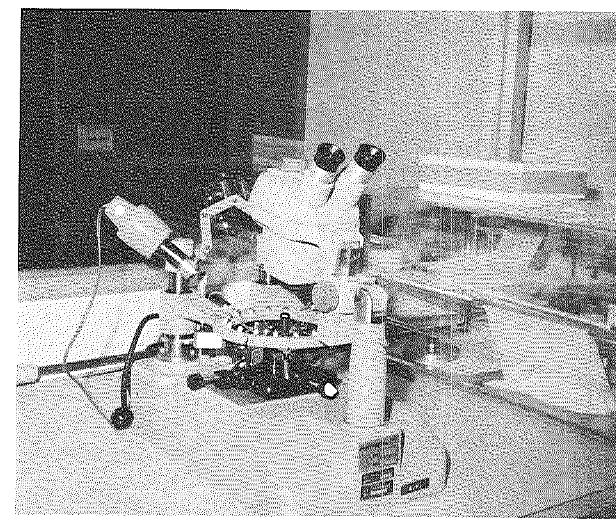


Figure 18.

ELECTRICAL TESTING



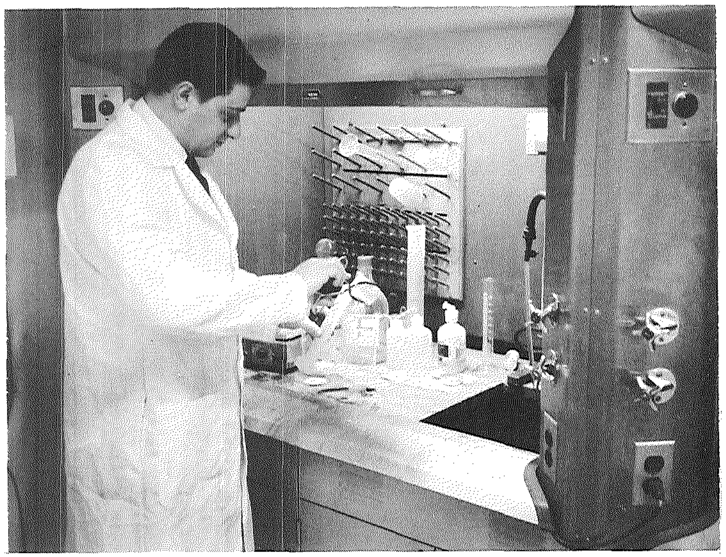
Birtcher IC Tester



Electrical probing equipment

Figure 19.

CHEMICAL LABORATORY

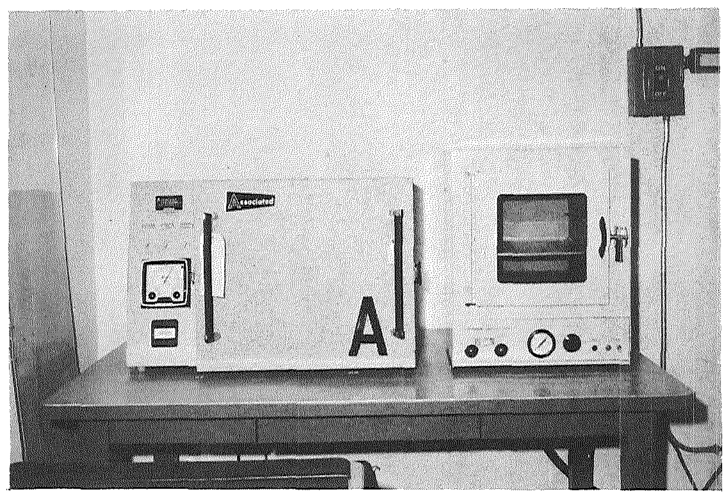


One of the chemical laboratories being used for failure analysis.

- Cleaning and various chemical treatments necessary during failure analysis.
- Staining and etchings of metallographical specimen, designed to bring out features of interest.
- Removal of metallization and oxide layers.
- Various plating processes.
- Specimen molding for metallographical purposes.
- Dissolving of epoxies used in the encapsulation of devices.

Organic Chemistry Laboratory

This laboratory, which is now being added to the Failure Mechanisms Branch, will be equipped to investigate failure mechanisms inherent in the use of polymeric materials for microelectronic applications.



Temperature cycling chamber (left) and vacuum oven (right).

Figure 20.